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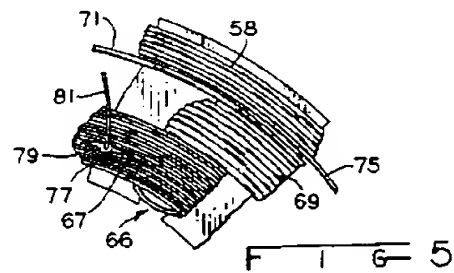
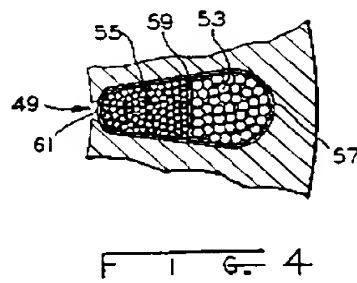
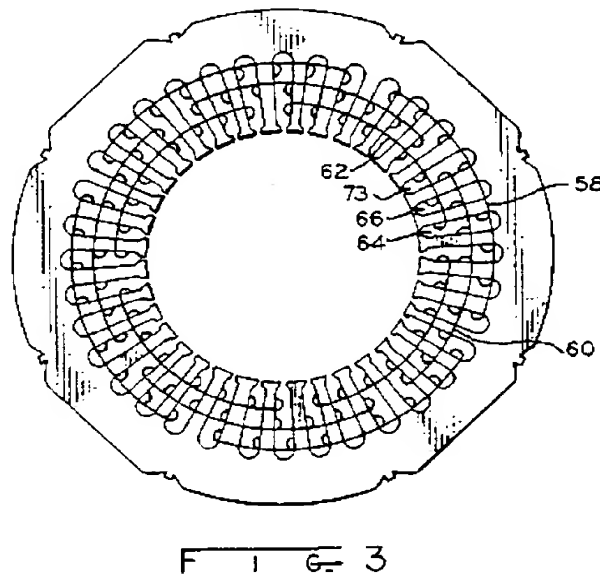
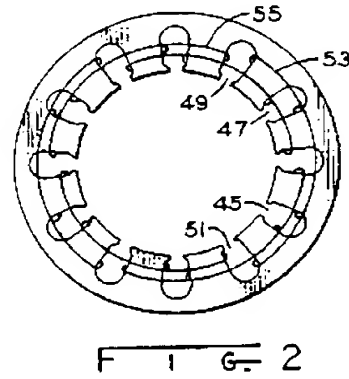
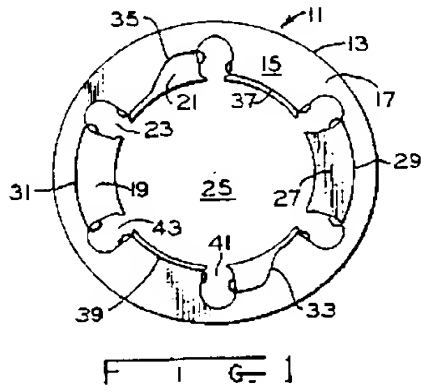
(54) Polyphase motors

(57) An alternating current dynamoelectric machine includes a plurality of phase windings placed in stator core slots with certain slots shared by more than one phase winding and a number of those shared slots having one phase winding portion disposed in the bottom part of the slot and a portion of another phase winding disposed in the upper part of the slot near the stator bore. This another phase winding comprises a greater number of turns of a smaller diameter wire as compared to the one phase winding. In one exemplary embodiment a three phase machine has concentric windings with the third phase wound with the same number of turns as the other two phases but with each turn comprising a bifilar or two strand turn of a lesser diameter wire. This arrangement lowers the injection forces required for placing the third phase in the stator core and also aids forming the third phase windings about a temperature sensor. All three phases may be wound of wire of similar materials.

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SPECIFICATION

Polyphase motors

- 5 The present invention relates generally to polyphase alternating current dynamoelectric machines and more particularly to a wound stator for such machines having concentric phase windings sharing certain stator core slots as well as to a method of providing phase windings for such a polyphase machine stator.
- 10 Polyphase dynamoelectric machines and especially three phase machines such as three phase motors or generators are old and well known in the art and such motors, for example, are frequently of the induction type having a squirrel cage rotor rotatably supported within a wound stator. In this type machine, the stator includes a magnetic core having a plurality of slots in which the stator windings are disposed. The stator windings are frequently of the lap winding variety where each stator slot contains a side portion of each of two different winding coils with one of those portions placed in the bottom of the slot close to the stator core yoke and the other of those winding portions is thereafter placed in that slot so as to lie closer to the stator bore. To obtain a well balanced machine, a given stator core has one of its side portions disposed in the bottom of a slot, while its other side portion is disposed in the top of a slot, so that the entire winding arrangement has these coils interleaved in a symmetrical manner. While such a lap winding provides very well balanced operating characteristics, the winding is not easily machine wound and inserted since each coil has to have one of its side portions inserted into the bottom of a slot and thereafter the other side portion of each coil is disposed in another slot on top of the first side portion of one of the other coils.
- 40 To take advantage of techniques for machine winding of the coils, either directly in the stator core slots or by using separate winding machines that establish coils which are thereafter inserted into stator core slots, several so-called concentric winding techniques have heretofore been employed in polyphase machine constructions.
- For reasons of economy, the same stator core as used in single phase induction motors may be used to fabricate, for example, a three phase induction motor with concentric windings. To obtain a good slot fill and therefore high efficiency with such a combination, coils of different phase windings will frequently share one or more slots in the stator core. Moreover, the coil which is radially innermost in a given slot (i.e., nearer to the bore) is frequently also radially innermost in its other slot and that phase winding coil therefore experiences lower slot leakage reactance than the phase coils disposed, for example, in the bottom of each of two slots, or the phase coil which may be disposed in the upper region of one slot and the lower or radially outermost region of another slot. An electrical imbalance results which may lower performance, create an unbalanced load on the three phase line, or give rise to other problems.

The imbalance associated with concentric winding arrangements have been recognized in the prior art and, for example, are disclosed in United States Patent Nos. 2,796,543; 2,947,894; and

- 70 3,439,205, all of which are commonly assigned to the assignee of the present invention. Techniques such as varying the number of turns in different coils and varying coil spans have been developed for minimizing phase current imbalance problems while providing equal slot fullness for optimum utilization of magnetic material and copper.

- Other problems manifest themselves when attempting to place as much current conducting material as possible in the stator core slots to maximize the efficiency of the dynamoelectric machine. 80 and salient among these is the physical problem of forcing the innermost (i.e., nearest to the bore) winding portions into slots already containing a substantial number of winding turns. While larger wire size coils are frequently easier to form and insert in a spacious slot region, they are correspondingly more difficult to form after insertion. An example of this difficulty would be the end turn forming of the coils after placement in the stator which is frequently mechanically accomplished by placing the stator over a so-called bullet, or which may be electromechanically accomplished.

- These several competing considerations frequently result in design compromises which have 95 included, for example, the winding of the third or innermost phase winding from conductors of a material different from that used for the other two phase windings, as well as the forming of all three phase windings by double stranding or bifilar techniques.

- However, double stranding all three phases often creates problems during placement of the windings in a slotted stator core. In a typical machine placement operation, a first phase winding may be inserted within selected core slots and then machine pressed back into the slot by an apparatus (such as disclosed in commonly assigned Bale Patent No. 4,003,116, the entire disclosure of which is incorporated herein by reference) in preparation for subsequent placement of insulating wedges and phase insulation. The winding portions within the selected slots are again pressed to allocate space for subsequent insertion of another winding. When double stranded wire is employed for the first phase to be inserted, the smaller diameter wire may get trapped between walls of the stator core slots and blades of the apparatus performing the pressing operation. When the wire becomes trapped, the insertion operation is halted and generally the entire winding must be scrapped due to damage to the wire insulation. Further, forming a winding by double stranding conductor means that twice as many wires are needed which increase the likelihood of the wires becoming entangled with insulating slot liners.

- One approach to alleviate the problems of trapped or entangled wires which halt the winding insertion operation and cause wire damage may be to modify the pressing equipment to press only smaller diameter wire. However, advantages can

often be gained by fabricating windings from a single strand of conductor, thus making it undesirable to fabricate all the windings from double stranded wire. For example, winding double strands of conductor requires twice as many feed sources such as spools or barrels of wire which creates a problem of the different feed sources running empty at different times. When one source runs empty before a winding is established, the winding portion already established must be scrapped including the wire from the source that did not run empty and the winding must again be formed. Since wire is generally sold by weight, the wire length may vary due to manufacturing tolerances; thus, significant scrap wire may result during the winding operation especially where the feed source is a large quantity of wire such as a barrel of wire.

However, other problems often occur when attempting to form all three windings from single stranded conductors. The first winding is relatively easily inserted into the empty slots of a stator core. The second phase winding is then inserted but with somewhat more difficulty because portions of the end turns of the first winding must be traversed by end turn portions of the second winding during their insertion. However, insertion of the third phase winding is often quite difficult, especially in situations where maximum slot fill is desired. The insertion forces required for the third phase winding would be much greater than for the first and second phase windings because end turns of the phase windings restrict or interfere with the movement of the third phase winding. The above-discussed problems would manifest themselves even more in fabricating a motor employing windings formed of non-copper wire such as aluminum or aluminum alloy wire. In many instances, it is desirable from the standpoint of economy to fabricate as many windings as possible from a non-copper material. However, the problems such as maximization of slot fill, winding insertion, and deformability for compressing end turns and or mounting of thermal protective devices become more acute because a wire formed of a non-copper material must generally be of a larger diameter in order to obtain the current carrying capability of copper wire.

One known approach to alleviating the above-mentioned problem encountered when employing non-copper wire in a multiphase motor has been to wind one phase normally the last to be inserted phase with copper wire while using non-copper wire for the remaining phases. However, the use of copper wire for one phase prevents the achieving of maximum economical benefits which could result from fabricating all the windings from non-copper material. Still further, the use of a non-copper material and copper material for windings can contribute to additional problems in making electrical connections involving dissimilar materials.

Accordingly, one of the objects of the present invention is to provide a polyphase stator arrangement which reduces electrical imbalance while faci-

litating winding formation and subsequent winding insertion fabricating techniques.

In accordance with one aspect of the present invention there is provided a stator for use in a polyphase alternating current dynamoelectric machine, the stator comprising: a magnetic core having a yoke, a number of teeth extending radially inwardly from the yoke and terminating at a rotor accepting bore, and coil accommodating slots established between each adjacent pair of teeth; three phase windings, including one phase winding and another phase winding disposed in at least some of the coil accommodating slots; at least one slot being shared by portions of at least two of the three windings; the at least one slot having a portion of one phase winding disposed in the bottom part of the slot near the yoke and a portion of another phase winding disposed in the upper part of the slot near the bore; and the another phase winding comprising a greater number of turns of a smaller diameter wire as compared to the one phase winding.

In accordance with a further aspect of the present invention there is provided a method of fabricating a polyphase dynamoelectric machine stator comprising: forming first coils having turns of a conductor of a first size; disposing the first coils into a first combination of slots of a magnetic core to form a first phase winding; forming second coils having turns of a conductor of either the first size or a second size smaller than the first size; disposing the second coils into a second combination of slots of the magnetic core to form a second phase winding; forming third coils of a conductor of the said second size and disposing the third coils into a third combination of slots of the magnetic core to form a third phase winding, the number of turns of the second size conductor coils being greater than the number of turns of the first size conductor coils, and at least one of the third combination of slots also being included in the first or second combination of slots.

The coils may be formed according to any of the several known prior art techniques, and their insertion or placement in the slots may be sequential or contemporaneous, as desired.

In one preferred embodiment of the present invention, a temperature sensor is nested or disposed in the end turns of a phase winding of the relatively smaller diameter conductor to provide good heat transfer between the winding and the temperature sensor.

By way of example only, several embodiments of the invention will now be described with reference to the accompanying drawings in which:—

Figure 1 is an end view of a simplified stator having a three phase two pole winding illustrated therein;

Figure 2 is a view similar to Figure 1 but illustrating a twelve slot stator having a three phase two pole winding disposed therein;

Figure 3 illustrates a thirty-six slot stator core having a three phase four pole winding therein;

Figure 4 is a sectional view of a portion of a stator core illustrating one slot shared by coils from diffe-

rent phase windings; and

Figure 5 is a view of the end face portion corresponding to the slot illustrated in Figure 4.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawing.

Figures 1-3 schematically illustrate different three phase motor winding arrangements with individual coils of the different windings being illustrated as a single winding turn. Further, the stator cores illustrated in Figures 1-3 may be of substantially conventional construction and may be formed, for example, of a stack of laminations of magnetic material.

Figure 1 illustrates a highly simplified three phase two pole stator having one coil per pole. In Figure 1, the stator 11 includes a magnetic core 13 having opposed end faces such as 15 with an annular yoke section 17. This yoke section has a number of teeth sections such as 19 and 21 extending radially inwardly from the yoke section 17 that form coil accommodating slots such as 23 between adjacent pairs 19 and 21 of tooth sections. These teeth sections extend inwardly from the yoke section and terminate at a generally cylindrical rotor accepting bore 25.

In Figure 1, a dynamoelectric machine pole happens to coincide with a single coil pole such as 29 formed about a single stator tooth such as 27. The phase winding for one phase of this three phase machine comprises coils 29 and 31, while a second phase winding comprises coils 33 and 35 with coils 37 and 39 forming the third phase winding. The windings in stator core 13 could be formed by in slot winding techniques or could be formed outside the stator core on a winding form or mold and thereafter inserted into the stator core by known coil injection techniques. Each winding could be inserted individually or all three windings could be inserted into the stator core during one coil injection step. Similarly, the interpole connections between the windings for two poles of the same phase may be accomplished during an external winding operation or may be connected after the coils are in place as desired.

Whether inserted by multiple or single pass injections or in slot winding techniques, each winding of Figure 1 has portions thereof which share stator slots with portions of the other windings. As illustrated, coils 29 and 31, which comprise the first phase winding have both legs or winding portions toward the bottom of their respective slots (i.e., near the yoke section) since this phase winding is inserted first in the stator core. Coils 33 and 35, which comprise the second phase winding, each have one leg disposed toward the bottom of respective slots while the other leg of each of these coils is closer to the stator bore since that other leg shares a slot with a portion of previously inserted coils 29 and 31. Since coils 37 and 39, which comprise the third phase winding, are the last to be placed in the stator core, their opposed leg portions are both placed in the top portion of their respective slots (i.e., nearest the bore 25) with the bottom or radially outer portion of those slots having pre-

viously been occupied by portions of either the first or the second phase windings. Thus, for example, slot 41 contains near the bottom thereof, one portion of coil 33, while the upper or inner portion of slot 41 is occupied by one leg of coil 39. Coil 39, on the other hand, occupies the upper or inner region of both slots 41 and 43.

As pointed out earlier, larger size wire is relatively easily inserted in a spacious slot region, however, when slot fill become relatively high, it may be easier to insert a larger number of turns of a smaller diameter wire. Further, the larger number of turns of a smaller diameter wire have more readily formable end turn portions. Thus, in order to facilitate winding insertion and enhance winding formability, the coils 37 and 39 comprising the third phase winding would be formed with a greater number of turns of smaller diameter wire than either the coils 29 and 31 which comprise the first phase winding or the coils 33 and 35 which comprise the second phase winding. Such a choice would provide for example in slot 41 a cross-sectional conductor arrangement of the type illustrated in Figure 4 which will be discussed more fully hereinbelow in reference to Figure 2. The smaller diameter wire would be selected so that when portions thereof are connected in parallel, the third phase winding would have approximately the same resistance and conductor cross-sectional area as the first and second phase windings. For example, if the third phase winding were formed from double strands of smaller conductor wire connected in parallel, the smaller size wire would have approximately one-half the cross-sectional area of the wire employed to form the first and second phase windings.

Figure 2 illustrates a three phase, two pole motor in which each pole thereof includes a pair of generally concentric coils. For example, one pole of a first phase winding may include the coil which spans from slot 45 to slot 47 and additionally the coil spanning between slots 49 and 51. Each slot depicted in Figure 2 is shared by windings of two different phases. Thus, slot 49 contains the outer coil 53 of the first phase as well as the outer coil 55 of a second or intermediate phase. Slot 47 contains the inner coil of a third phase winding as well as the inner coil of the first phase winding. Figure 2 illustrates a situation in which it may be desirable to form both the third and second phase windings from a smaller diameter conductor and of a greater number of turns, for example, by double stranding, as compared to the first phase winding since each winding has coils which share slots with coils of the first phase winding. Thus, forces required for inserting the second and third phase windings after insertion of the first phase winding would be reduced.

Figure 4 illustrates the slot 49 of Figure 3 with the multiple turns of the coils 53 and 55 being depicted. Slot 49 has an insulated lining 57 which may be provided by a dipping or coating process or may simply comprise an inserted slot liner formed from electrical insulating material such as, for example, the material marketed under the trademark "MY-

LAR" by E. I. DuPont de Nemours and Company. The coil 53 of the first phase winding is first disposed in the slot near the bottom thereof (i.e., near the yoke). The coil 53 is then pressed to allocate 5 space for insertion of a phase insulating wedge 59 which may for example be of the type illustrated in the aforementioned United States Patent No. 3,438,206. The coil 53 is again pressed to allocate space for insertion of the second phase winding 10 coil 55. The smaller diameter wires forming the coil 55 have greater pliability than the larger wires of the coil 57, thus reducing insertion forces and facilitating placement of the coil 55 into the slot 49. A bore wedge 61 may optionally be placed in the slot 15 to hold the conductors of coil 55 in place and prevent damage to those conductors. As clearly illustrated in Figure 4, coil 53 is formed of a larger diameter wire and of a lesser number of conductors as compared to coil 55. These coils may be formed 20 and placed in stator cores, for example employing the equipment and techniques illustrated in commonly assigned United States Patent No. 3,510,939 to Dallas F. Smith, the entire disclosure of which is incorporated herein by reference, as well as by 25 other known winding techniques.

One way of fabricating the arrangement illustrated in Figures 2 and 4 would be to wind a coil such as 53 of a single strand of relatively large diameter aluminum wire and then with the same 30 equipment, wind the same number of turns to form a coil such as 55 from a two strand or bifilar supply so that the number of turns of coil 55 is twice the number of turns of coil 53. Whether the number of turns for different coils in a given slot is in the ratio 35 of two to one depends upon the particular stator configuration and as will appear from the discussion of Figure 3, the particular slot under consideration.

The stator depicted in Figure 3 is for a four pole, 40 three phase machine with concentric windings disposed in the thirty-six slots of that stator. The coils for the windings are illustrated as single turns of conductor wire although it is to be understood that the coils may be comprised of multiple turns of 45 conductor wire. Each pole group for this stator arrangement is formed of four concentric coils with a first phase winding including pole group 58 having all of its coils disposed in the bottom or outermost portion (i.e., nearest the stator yoke) of the 50 occupied stator slots. The coils for this first phase winding are formed of a relatively large diameter wire. The second or intermediate phase winding illustrated as having a pole group 60 has most of its coils disposed radially inward (i.e., toward the 55 bore) relative to the coils of the first phase winding occupying the same slots. The inner or third phase winding, including pole group 62 for example, will have all of its coils disposed radially innermost (i.e., nearest the bore) in any stator slot. Two-thirds or 60 twenty-four of the slots of the stator illustrated in Figure 3 contain sides or side turns of coils from all three phases while the remaining twelve slots contain coil portions from two of the three phases. The third phase illustrated as including pole group 62, 65 are formed, for example, as a two strand winding

having the same number of revolutions and therefore twice the number of conductor turns of a smaller diameter wire as compared to the first phase winding, illustrated as including pole group 58. The 70 second phase winding may be formed identical to the outer phase winding.

Each of the twelve slots containing coil portions from only two phases contains not the outermost coil of those phases but the next inner concentric 75 coil from those phases. Thus, the outermost coil of pole group 62 has one leg thereof disposed in slot 64 while the next inner coil of pole group 62 has one leg thereof placed in slot 66. Slot 66 contains the next to the outer coil of pole group 60 but does 80 not contain any coils associated with pole group 58. Thus, this next to the outer coil for each phase may be formed of a greater number of turns than the remaining three coils for that pole to obtain a maximum slot fill for the stator.

The relatively tightly packed slot 66 of Figure 3 is illustrated in more detail in Figure 5. Referring to Figure 5, the slot 66 has a coil 67 of the pole group 62 disposed within the slot near the bore, i.e., next to the open end of the slot. Coil 69 of the pole group 90 60 is also disposed within the slot with side turns thereof being located radially outward or within the closed end of the slot. End turns in the region of this slot have for better visualization been formed outwardly and include coil 71 which is the outermost coil of pole group 60 and which is destined for slot 73 (Figure 3). The outermost coil of pole group 62 is coil 75 which is destined to pass into slot 64 (Figure 3). End turns of pole group 58 are also present.

The relatively more easily formed coil 67 has in Figure 5 been spread apart, and a temperature sensor 77 has been embedded between the turns thereof. Because smaller diameter wire was employed to form the third phase winding including 105 coil 67, the end turns may be formed about the sensor or thermal protector to create good contact therewith and thereby facilitate efficient heat transfer from the winding 67 to the thermal protector 77. This thermal protector 77 is provided with fins 79 110 extending therefrom to improve the heat transfer characteristics from the winding 67 to the sensor 77 and further provided with conventional leads 81 extending therefrom to thermal protector circuitry of a conventional type. It is easier to place the temperature sensor 77 in coil 67 as compared to the relatively larger wire of, for example, coil 58, because 115 of the pliability of the smaller diameter wire of coil 67. Further, the coil 67 is more easily compressed about and into good heat transfer relation with the temperature sensor due to the smaller wire size in this coil. 120

Further advantages accrue when the third phase winding, that is the phase winding including pole group 62 of Figure 3, is formed of a greater number 125 of turns of relatively smaller diameter wire. The first and second phase windings are generally disposed or inserted first into the stator slots. Thus, the coils of the third phase winding must be moved past end turns of the other two windings during 130 their insertion. The use of smaller diameter wire

makes the coils of the third phase winding more pliable and thus, reduces the interference with the other two windings which in turn reduces the required injection or insertion force. Further, the use of smaller diameter wire facilitates deformation of the third phase winding away from the stator bore in order to allow for subsequent mounting of a rotor within the bore.

As a specific example, a typical three phase motor stator having a range of 24 to 36 slots may have its first and second phases wound of a single strand of copper wire having a cross-sectional diameter of .0671 inches. The third phase may be wound from a double strand of copper wire with each wire having a cross-sectional diameter of .0403 inches. Assuming contrary to the actual fact that no magnetic imbalance due to differing slot locations for differing phases is present, the theoretical diameter for this inner phase (assuming twice the number of turns due to the bifilar winding thereof) to provide an equal total conductor cross-section for each phase would be $.707 \times$ the diameter of the larger wire or .0403 inches and this choice works well in actual practice. Another practical three phase motor has been constructed employing a larger wire diameter of .0605 inches and a smaller wire diameter of .0427 inches with this diameter ratio being again $.707$ or one-half the square root of two.

The above-mentioned specific examples of constructed motors may be fabricated using non-copper conductor materials, for example, aluminum and/or aluminum alloy conductor materials for the winding phases. When employing the same conductor material, the wire for the third phase would be selected to have approximately one-half the cross-sectional area of the wire employed to form the first and second phases. Thus, the third phase, when formed with double strands of the smaller wire, would have approximately the same resistance and conductivity as each of the single stranded second and first phases. By double stranding the innermost phase and single stranding the remaining phases, insertion of the winding in slots which share or contain the windings is facilitated. Further, by utilizing similar rather than dissimilar materials (for example, one winding of copper and another of aluminum), electrical connection problems associated with connection of dissimilar materials are minimized. Still further, the smaller diameter wire, as mentioned previously, is more easily deformed than the larger diameter wire, thereby allowing disposition of a temperature sensor within the second phase winding so that a good thermal relationship between the winding and sensor is established.

The described embodiments may be practiced in conjunction with other techniques such as, for example, short pitch windings to eliminate certain harmonic currents in the stator windings as well as, for example, the features and techniques disclosed in the aforementioned trio of United States Patents for achieving better phase balance between the phases.

85 CLAIMS

1. A stator for use in a polyphase alternating current dynamoelectric machine, the stator comprising: a magnetic core having a yoke, a number of teeth extending radially inwardly from the yoke and terminating at a rotor accepting bore, and coil accommodating slots established between each adjacent pair of teeth; three phase windings, including one phase winding and another phase winding disposed in at least some of the coil accommodating slots; at least one slot being shared by portions of at least two of the three windings; the at least one slot having a portion of one phase winding disposed in the bottom part of the slot near the yoke and a portion of another phase winding disposed in the upper part of the slot near the bore; and the another phase winding comprising a greater number of turns of a smaller diameter wire as compared to the one phase winding.

2. The stator of claim 1 wherein two of the three phase windings have substantially the same number of turns of substantially the same diameter wire, and the remaining phase winding has a greater number of turns of a smaller diameter wire.

3. The stator of claim 1 wherein each phase winding comprises groups of concentric coils.

4. The stator of claim 1 further comprising a temperature sensor nested within end turns of the said another phase winding.

5. The stator of claim 1 wherein the three phase windings are formed from wire of the same material.

6. The stator of claim 1 wherein each of the three phase windings is formed from wire of a non-copper material.

7. The stator of claim 1 wherein the at least one slot has portions of the three phase windings disposed therein.

8. A method of fabricating a polyphase dynamoelectric machine stator comprising: forming first coils having turns of a conductor of a first size; disposing the first coils into a first combination of slots of a magnetic core to form a first phase winding; forming second coils having turns of a conductor of the first size; disposing the second coils into a second combination of slots of the magnetic core to form a second phase winding; forming third coils of a conductor of a second size smaller in diameter than the conductors of the first size and of a greater number of turns than the first and second coils; and disposing the third coils into a third combination of slots of the magnetic core to form a third phase winding with at least one of the third combination of slots also being included in the first or second combination.

9. The method of claim 8 wherein the first coils, the second coils and the third coils are disposed substantially contemporaneously with one another within slots of the magnetic core by axially passing those coils into the magnetic core slots.

10. The method of claim 8 wherein the forming of the third coils comprises winding a pair of conductor strands of the second size about a coil form to provide a bifilar phase winding.

11. The method of claim 10 wherein the forming of the first coils and the second coils includes winding single stranded conductors about a coil form with the number of revolutions in forming each of the first and second coils and in forming the second coils being substantially equal, and thereby providing substantially twice as many conductor turns in the second coils as there are conductor turns in each of the first and second coils.
12. The method of claim 8, further including placing a temperature sensor between end turn portions of the third coils and forming end turn portions of the third coils to establish good heat transfer relationship with the temperature sensor.
13. A method of fabricating a polyphase dynamoelectric machine stator comprising: forming first coils of a conductor of a first size; disposing the first coils into a first combination of slots of a magnetic core to form a first phase winding; forming second coils of a conductor of a second size smaller in diameter than the conductor of the first size conductor and of a greater number of turns than the first coils; disposing the second coils into a second combination of magnetic core slots to form a second phase winding; forming third coils of a conductor of the second size; disposing the third coils into a third combination of slots of the magnetic core to form a third phase winding with at least one slot of the third combination also being included in the first combination.
14. The method of claim 13 wherein the disposing of the first coils, the second coils and the third coils is performed substantially contemporaneously within slots of the magnetic core by axially passing those coils into the magnetic core slots.
15. The method of claim 13 wherein the forming of the third coils comprises winding a pair of conductor strands of the second size about a coil form to provide a bifilar phase winding.
16. The method of claim 13 wherein forming of the first coils includes winding a single conductor about a coil form with the number of revolutions in forming the first coils and in forming the third coils being substantially equal, and thereby providing substantially twice as many conductor turns in the third coils as there are conductor turns in the first coils.
17. The method of claim 13, further including placing a temperature sensor between end turn portions of the third coils and forming end turn portions of the third coils to establish good heat transfer relationship with the temperature sensor.

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